CNES Earth Exploration missions using the X-band for payload telemetry

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Outlines

- In-orbit missions
  - Spot
  - Demeter
  - Parasol
- Future missions
  - Pleiades
- Payload telemetry : Requirements for future missions
  - Data rate
  - Source coding and BER requirements
- Conclusion

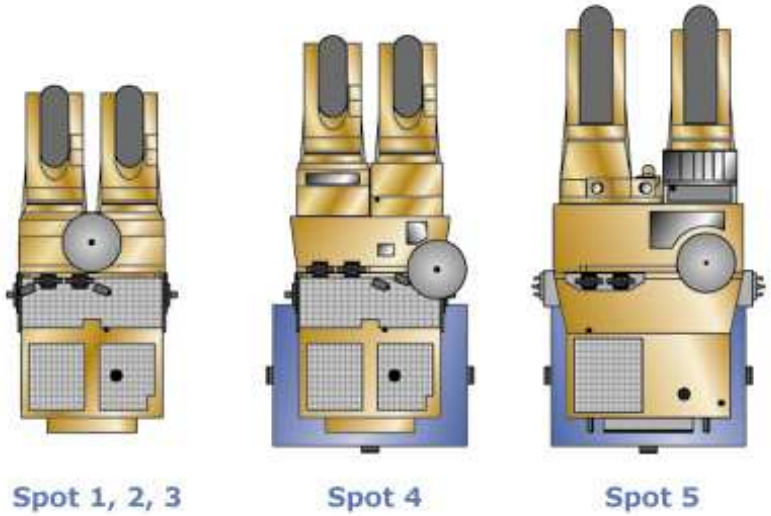
In-orbit missions : Spot

Operational Earth observation system

- ⇨ Propose high-image-quality products
- ⇨ Continuity of service since 1986
- ⇨ Imaging instrument to pick up object on the ground no larger than few meters with spot 5
- ⇨ Orbit : LEO (822 km), near polar (98.7° inclination) , phased (26-days cycle) and sun-synchronous (10:30 a.m)
- ⇨ Applications :
  - Agriculture
  - Urban planning
  - Geology, oil, mineral exploration
  - Costal study and oceanography
  - Mapping and 3D
  - Forrest management
  - Natural disaster management
  - Water resources management

In-orbit missions : Spot

In-orbit missions : Spot



Spot 1, 2, 3 Spot 4 Spot 5

- Studies and developments start in 1978
- Spot 1 launched in February 1986, operated during 17 years and dis-orbited in 2003
- Spot 2 launched in January 1990
- Spot 3 launched in September 1993 (last image : November 1996)
- Spot 4 launched in March 1998
- Spot 5 launched in April 2002

In-orbit missions : Spot

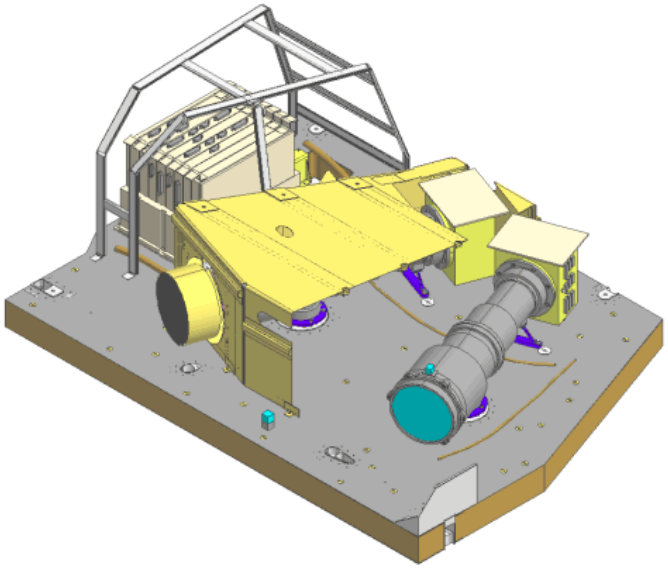
Satellite	Spot 1,2,3	Spot 4	Spot 5
Total mass	1800 kg	2760 kg	3000 kg
High-resolution instrument			
	2 HRV	2 HRVIR	2 HRG
Spectral bands	1 panchromatic (10 m) 3 multispectral (20 m)	1 panchromatic (10 m) 3 multispectral (20 m) 1 short-wave infrared (20 m)	1 panchromatic (2.5 to 5 m) 3 multispectral (10 m) 1 short-wave infrared (20 m)
Swath	2 x 60 km		
Revisit interval	2 to 3 days		
Onboard image processing	Two images processed concurrently, then downlink or recorder		Up to 5 images (2 downlinked and 3 stored)

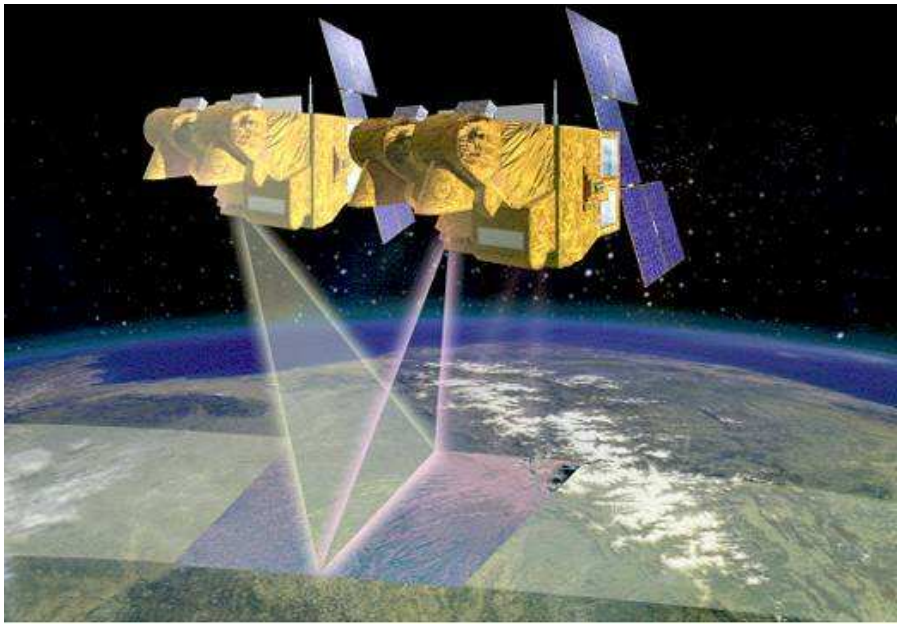
In-orbit missions : Spot

Satellite	Spot 1,2,3	Spot 4	Spot 5
Payload telemetry bay / TTC			
Recording capacity	2 x 60 Gbits recorder 160 images	120 Gbits recorder (nominal + redondant) 9 Gbits solid-state memory 400 images	90 Gbits solid-state memory 550 images
Payload telemetry	50 Mbits/s	50 Mbits/s	2 x 50 Mbits/s
Transmitter	Uncoded differential QPSK @ 8253 MHz	Uncoded differential QPSK @ 8253 MHz	Differential QPSK + BCH (252,236) @ 8153 MHz @ 8253 MHz
Telemetry	2048 bps	4096 bps	4096 bps
Telecommand	20 words / sec	60 words / sec	60 words / sec

In-orbit missions : Spot

- HRS instrument
  - On-board sensor for Spot 5
  - Designed to acquire images in the panchromatic band at viewing angles of 20° forward and aft of the satellite. It can thus ob tain stereopair images quickly to generate digital elevation models.





In-orbit missions : Spot

- Vegetation
  - On-board payload for Spot 4 and 5
  - Imaging instrument with four cameras operated in four spectral bands :
    - Blue, mainly to perform atmospheric corrections
    - **Red and Near Infrared (NIR)**, sensitive to the vegetation's photosynthetic activity and cell structure
    - **Short Wave Infrared (SWIR)**, sensitive to soil and vegetation moisture content.
  - SPOT 5 and VEGETATION (8153 MHz - BPSK - 3.4 Mbps) payload telemetry signals are frequency-division-multiplexed and transmitted by SPOT 5's X-band antenna

In-orbit missions : Demeter

DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) is the first project in the CNES Myriade micro-satellite series.

The scientific purpose of the mission is to :

- study the ionospheric disturbances related to seismic activity,
- study the ionospheric disturbances related to human activity,
- study the pre- and post-seismic effects in the ionosphere,
- contribute to understand the mechanisms generating those disturbances,
- give global information on the Earth's electromagnetic environment at the satellite altitude.

Technical payload is also on-board to test and validate new technologies

In-orbit missions : Demeter

- Launched in June 2004
  - Mission lifetime : 2 years
  - quasi sun synchronous circular orbit (inclination 98.23°) at 715 Km, with an ascending node at 22h15.
- Based on the myriades platform
  - Mass : 130 kg
  - 8 Gb solid-state memory
- Payload telemetry link :
  - 16 Gbit/day (Scientific mission) and 8 Gbit/day (technological mission)
  - High rate data transmission 16,8 Mbits/s
  - 4D 8PSK-TCM with Reed-Solomon RS(254,338) coding
  - Output spectrum shaped with a microwave filter (see SFCG 21-2)

In-orbit missions : Parasol

Mission objectives :

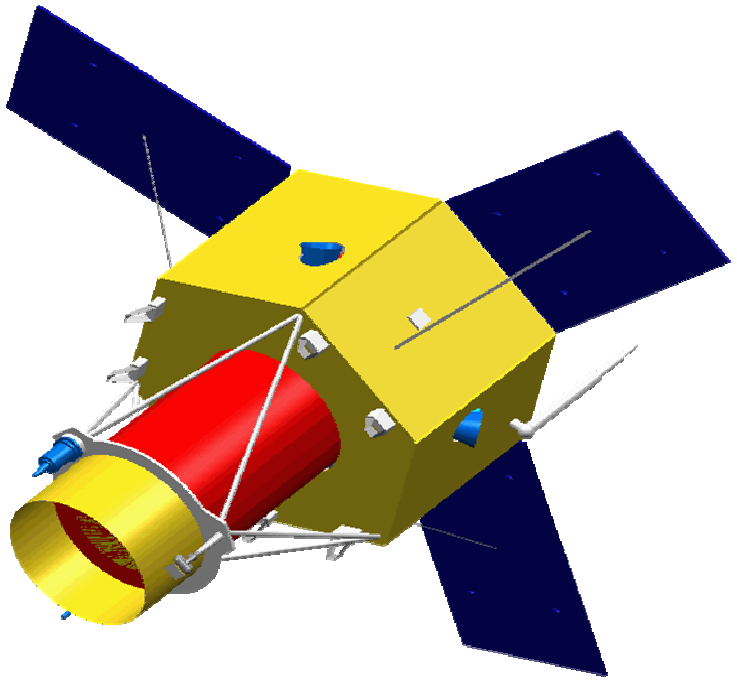
- Characterize the radiative properties of clouds and aerosols
- Perform measurements of the polarized and multi-directional reflectances, on areas observed by the LIDAR on board CALIPSO as a priority.
- Complementarities with the other instruments in the A-train formation

Satellite :

- Based on the myriades platform
- 16 Gbits solid-state memory
- High rate data transmission 16,8 Mbits/s
- 4D 8PSK-TCM with Reed-Solomon RS(254,338) coding
- Output spectrum shaped with a microwave filter (see SFCG 21-2)

Future missions : Pleiades

- Space Segment
  - one-metre resolution (20-km swath)
  - other overflight in the next 24 hours requires two HR satellites
  - daily acquisition capacity of 250 images per satellite
  - Mass: 900 kg
- Power
  - Lithium-ion batteries
  - Rigid gallium arsenide solar panels
- Attitude and orbit control subsystem
  - Gyro actuators
  - Star sensors
  - Fibre optic gyros
- Image telemetry at 489 Mbps
  - Three channels (163 Mbps)
  - 4D 8PSK TCM 2.5bit/Hz/s with a RS(254,238) code
  - Quasi iso-flux antenna
  - 600-Gbit mass memory
  - Wavelet compression (mean rate = 4)



Requirements : data rates

- Heavy Earth Exploration missions
  - Increase of the sensors' accuracy => Increase of the amount of data to be transmitted from the satellite to the ground station(s)
  - Increase of the data rate : 50 Mbps (Spot 1 – 1986) to 489 Mbps (Pleiades – end of 2008)
  - Long term requirements for data rate can reach 1 Gbps
- Small Scientific missions
  - Use of generic platform (Myriades)
  - Migration of the payload telemetry link from the S-band to the X-band
  - Current requirements for data rate is about 20 Mbps
  - Long term requirements for data rate can reach 150 Mbps and will be covered by existing equipments

Requirements : Source coding

Source coding for Earth Observation missions : compression algorithms from Spot to Pleiades :

	SPOT 1 - 4	SPOT5	PLEIADES-HR
Instrument	HRV	HRG	HR
Compression Algorithm	DPCM + fixed length coding	DCT + variable length coding	Wavelet Transform + Bit Plane Encoder
Resolution (PAN)	10 m	2.5 m	0.7 m
Data Rate	2 x 32 Mb/s	2 x 256 Mb/s	4.5 Gb/s
Dynamic Range	8 bits	8 bits	12 bits
Compression Ratio	1.33	2.82	~5

Requirements : BER

New image compression algorithms offer better image quality and compression ratios
BUT the compressed bitstream is much more sensitive to BER :

SPOT5 : Compression Rate ≈ 2.77 bit/pixel
Worst case impact of a bit in error in the bitstream : 1024 pixels

PLE-HR : Compression Rate ≈ 2.5 bit/pixel
Worst case impact of a bit in error in the bitstream : $120 \cdot 10^3$ pixels

The system Quality of Service is defined by user in terms of a maximum authorized decompressed pixel error ratio. Since the BER of recent on-board storage equipments (SSR) is extremly low, the overall QoS is mainly established by X-band telemetry performance

Roughly : $$\text{Required BER} = \frac{\text{User } \textit{Specified} \text{ Pixel Error Ratio}}{\text{Compression Rate} \times \text{Compressed Bitstream Sensitivity}}$$

This explains a typical BER requirement of 10^{-11} (DVB-S standard) :

- ✓ **Decompressed Pixel Error Ratio for SPOT5 compression algorithm : $2.8 \cdot 10^{-8}$**
- ✓ **Decompressed Pixel Error Ratio for PLEIADES-HR compression algorithm : $3 \cdot 10^{-6}$**

➔ On-board image compression is essential for high resolution Earth observation missions but it leads to high performance requirements for X-band telemetry systems.

Conclusion

Earth Exploration is a key application for space

Small and low cost platform

↳ need for low cost equipments

High resolution or large field optical and radar sensors

↳ need for higher data rate

New image compression algorithms

↳ need for lower bit error rates

More and more space vehicules using the X-band for payload telemetry

↳ protect from interference